Positrons - e^+p Physics with the LHeC

Ring: same $e^{\pm}p$ intensities, Linac: inferior positron intensity [cf talk of H.Braun]
(Why) does the LHeC physics programme require positrons – which intensity?

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Workshop Chavannes 14.6.2012

http://cern.ch/lhec

LHeC Physics -1

1. Grand unification? α_s to per mille accuracy: jets vs inclusive
   ultraprecision DIS programme: N^kLO, charm, beauty, ep/eD,..

2. A new phase of hadronic matter: high densities, small α_s
   saturation of the gluon density? BFKL-Planck scale
   superhigh-energy neutrino physics (p-N)

3. Partons in nuclei (4 orders of magnitude extension)
   saturation in eA ($A^{1/3}$?), nuclear parton distributions
   black body limit of F_2, colour transparency, …

4. Novel QCD phenomena
   instantons, odderons, hidden colour, **sea=antiquarks (strange)**

5. **Complementarity to new physics at the LHC**
   LQ spectroscopy, eeqq CI, Higgs, e^*

6. **Complete unfolding of partonic content of the proton**,
   direct and in QCD

Physics with e^+

LHeC Physics - 2

1. Neutron structure free of Fermi motion
2. Diffraction – Shadowing (Glauber). Antishadowing
3. Vector Mesons to probe strong interactions
4. Diffractive scattering "in extreme domains" (Brodsky)
5. **Single top and anti-top 'factory' (CC)**
6. Gluon density over 6 orders of magnitude in x
7. **GPDs via DVCS**
8. Unintegrated parton distributions
9. Partonic structure of the photon
10. **Electroweak Couplings to per cent accuracy**

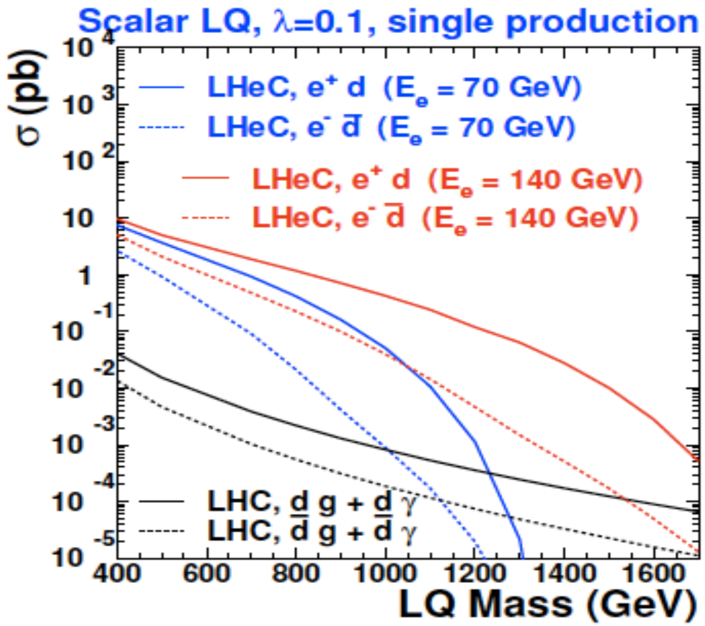
....

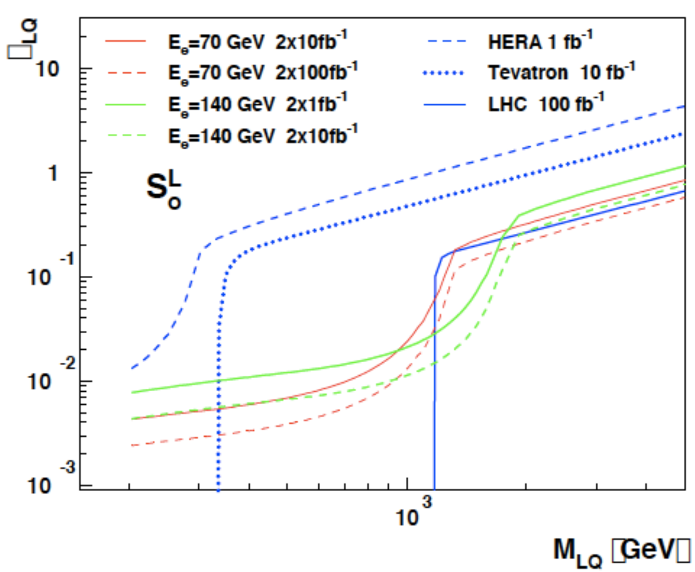
Every major step in energy can lead to new unexpected results, ep: SLAC, HERA

Requires: High energy, $e^{\pm}$, p, d, A, high luminosity, 4π acceptance, high precision (e/h)

↳ TeV scale physics, electroweak, top, Higgs, low x unitarity

Leptoquark Sensitivity





E6 new fields
TC bound states of technifermions
PS 4th colour of quarks
l,q composite models

The cross section in ep is (depending on couplings) 100 times higher than in pp, single production, but LHC is there, has pair production and higher energy

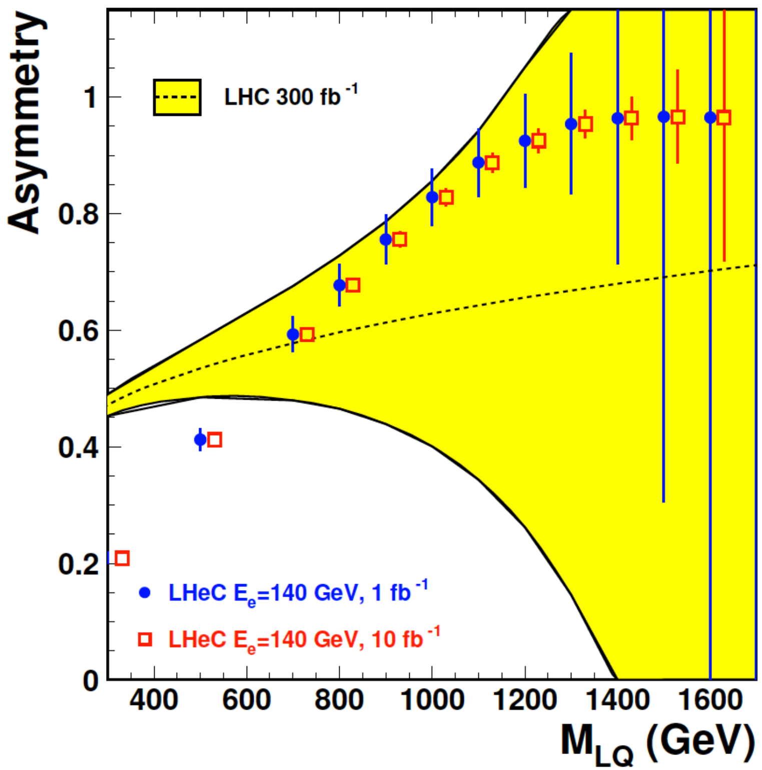
LHeC has mass reach up to about the cms energy (M < sqrt(s) = 1.3 .. 2 TeV for 60 .. 140 GeV electron beam energy)

→IF LQs are discovered at the LHC the electron beam energy would possibly be adjusted

→The role of ep would be primarily to determine the LQ quantum numbers

Leptoquark Quantum Numbers

$$A = \frac{\sigma_{e^-} - \sigma_{e^+}}{\sigma_{e^-} + \sigma_{e^+}} \begin{cases} > 0 \text{ for F=2} \\ < 0 \text{ for F=0} \end{cases}$$



Model	Fermion number F	Charge Q	$BR(LQ \to e^{\pm}q)$ β	Coupling		Squark type
$S_\circ^L$	2	$-1/3$	1/2	$e_L u$	νd	$\tilde{d}_R$
$S_\circ^R$	2	$-1/3$	1	$e_R u$		
$\tilde{S}_\circ$	2	$-4/3$	1	$e_R d$		
$S_{1/2}^L$	0	$-5/3$	1	$e_L \bar{u}$		
		$-2/3$	0		$\nu \bar{u}$	
$S_{1/2}^R$	0	$-5/3$	1	$e_R \bar{u}$		
		$-2/3$	1	$e_R \bar{d}$		
$\tilde{S}_{1/2}$	0	$-2/3$	1	$e_L \bar{d}$		$\bar{\tilde{u}}_L$
		$+1/3$	0		$\nu \bar{d}$	$\bar{\tilde{d}}_L$
S_1	2	$-4/3$	1	$e_L d$		
		$-1/3$	1/2	$e_L u$	νd	
		$+2/3$	0		νu	
$V_\circ^L$	0	$-2/3$	1/2	$e_L \bar{d}$	$\nu \bar{u}$	
$V_\circ^R$	0	$-2/3$	1	$e_R \bar{d}$		
$\tilde{V}_\circ$	0	$-5/3$	1	$e_R \bar{u}$		
$V_{1/2}^L$	2	$-4/3$	1	$e_L d$		
		$-1/3$	0		νd	
$V_{1/2}^R$	2	$-4/3$	1	$e_R d$		
		$-1/3$	1	$e_R u$		
$\tilde{V}_{1/2}$	2	$-1/3$	1	$e_L u$		
		$+2/3$	0		νu	
V_1	0	$-5/3$	1	$e_L \bar{u}$		
		$-2/3$	1/2	$e_L \bar{d}$	$\nu \bar{u}$	
		$+1/3$	0		$\nu \bar{d}$	

from CDR:

Fermion number (F) Since the parton densities for u and d at high x are much larger than those for $\bar{u}$ and $\bar{d}$, the production cross section at LHeC of an $F=0$ ($F=2$) LQ is much larger in e^+p (e^-p) than in e^-p (e^+p) collisions. A measurement of the asymmetry between the e^+p and e^-p LQ cross sections thus determines the fermion number of the produced leptoquark.

Contact Interactions

CI:

New interaction interfering

with the SM at some coupling:

charge asymmetry to disentangle

the nature of the new interaction.

Range linked to statistics.

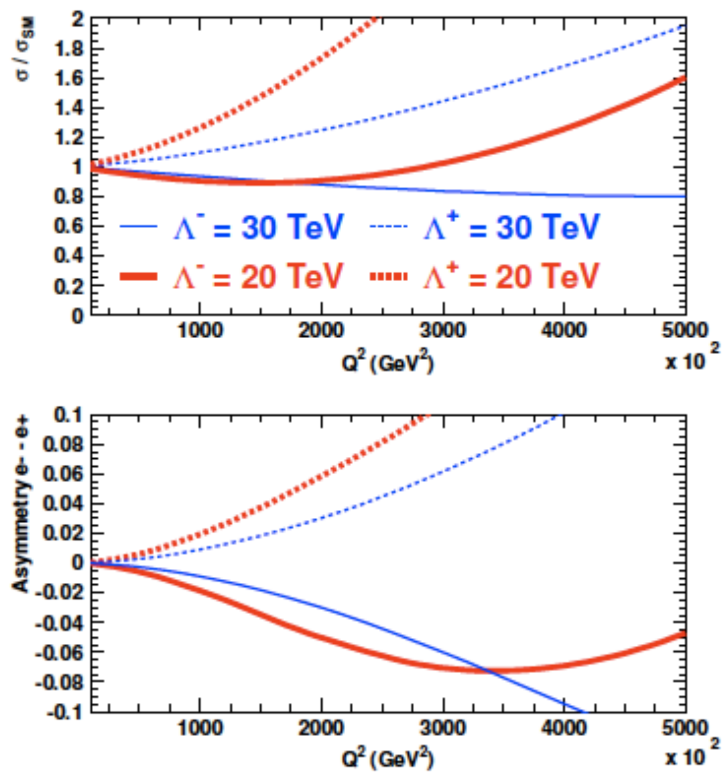
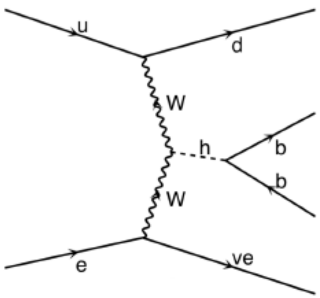
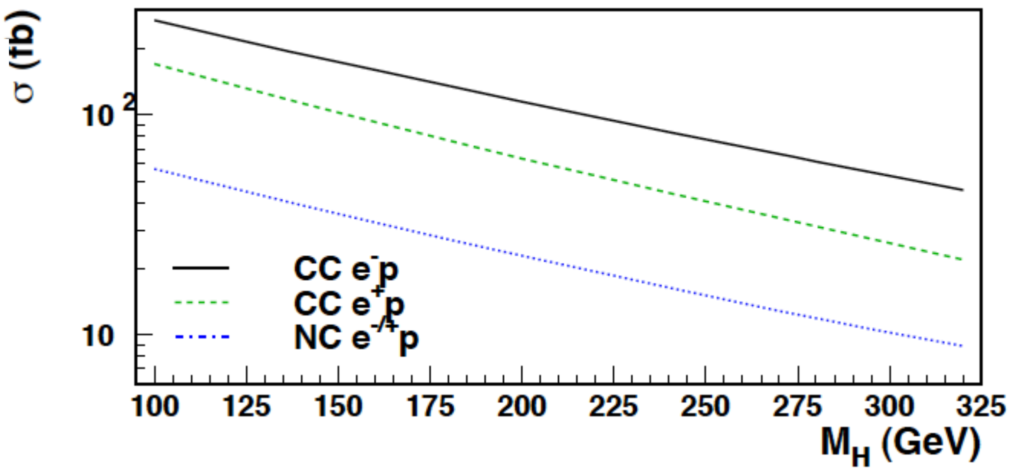
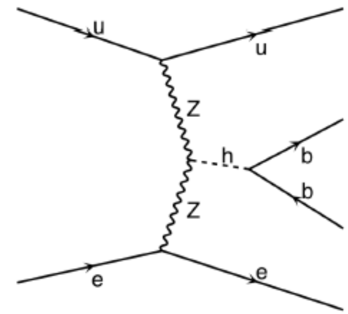


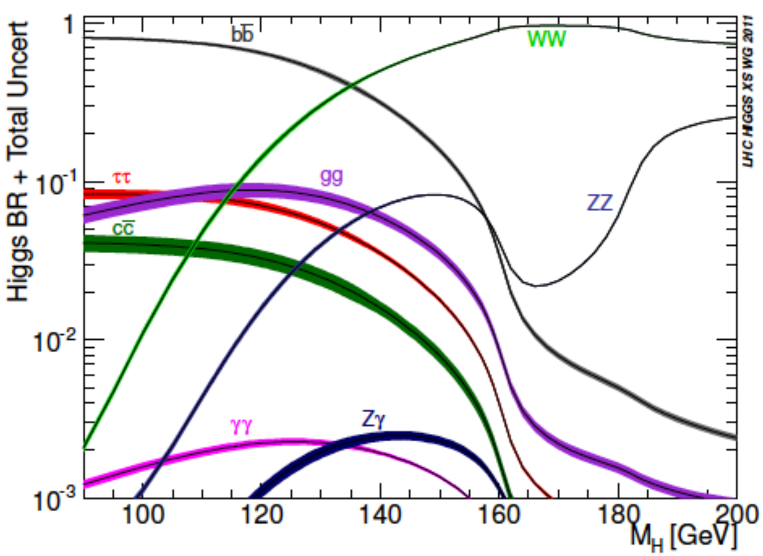
Figure 6.4: (top) Example deviations of the e^-p DIS cross-section at LHeC, in the presence of an $eeqq$ CI. The ratio of the "measured" to the SM cross-sections, $r = \sigma/\sigma_{SM}$, is shown. (bottom) Asymmetry $\frac{r(e^+)-r(e^-)}{r(e^+)+r(e^-)}$ between e^+p and e^-p measurements of σ/σ_{SM}.

Higgs Physics









CDR: H → bb analysis: 400 events for 100 fb^{-1} at 60 GeV e^-p polarised

More channels can be studied (WW, ττ).

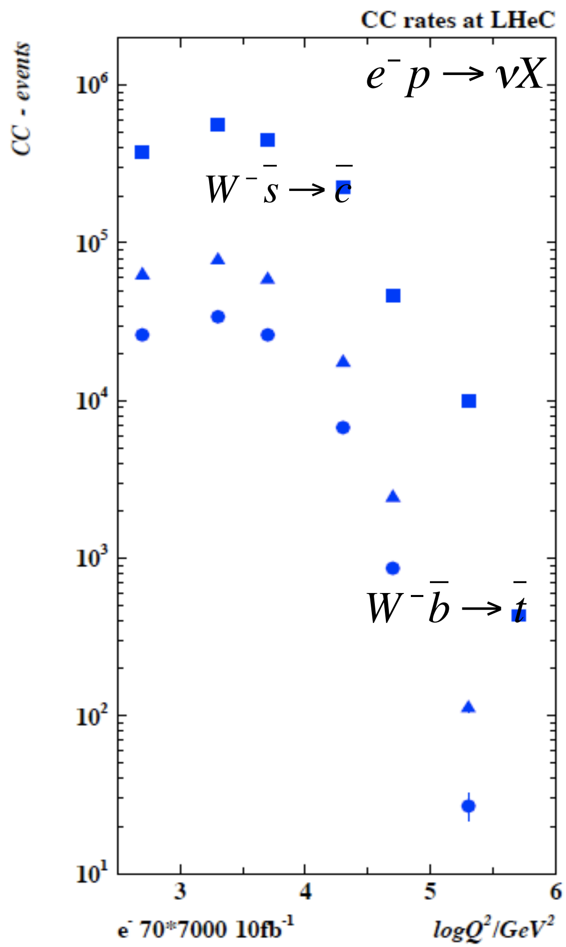
CC production in e^- larger than e^+

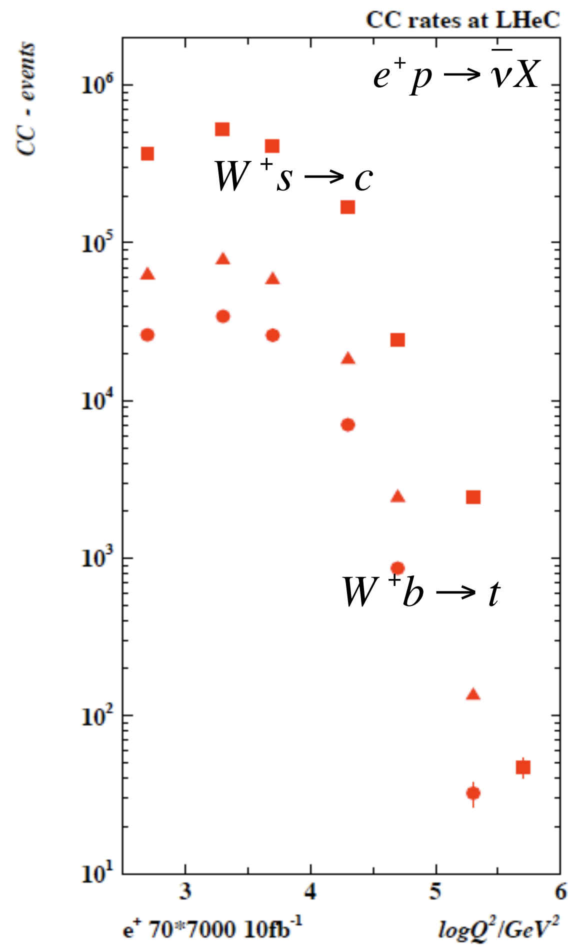
Want highest electron rate: Strong desire from Higgs boson (if it exists) for $L \approx 10^{34} cm^{-2}s^{-1}$ and long operation

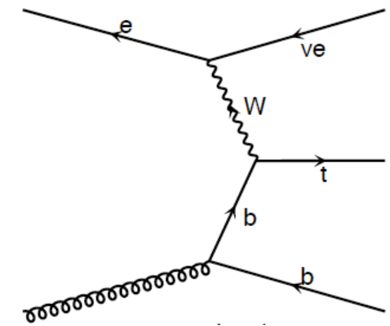
No evident demand for e^+ from Higgs. ??

$\overline{\text{Top}}$ and Top Production in Charged Currents

Charged currents are flavour sensitive: beam charge selects up and down and (anti)-quarks







LHeC is a single top and anti-top quark factory

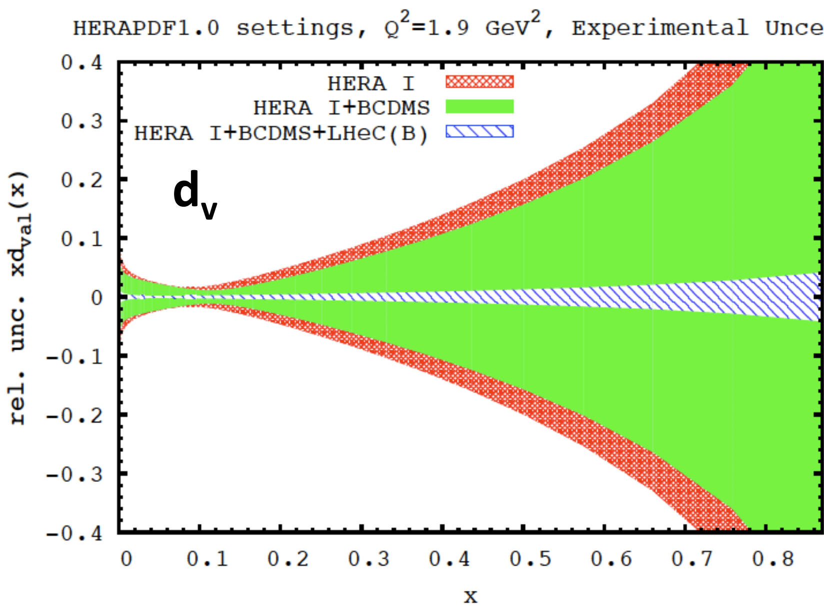
with a CC cross section of O(10)pb

Study Q^2 evolution of top quark onset – 6 quark CFNS

Can do top less differential.

Not measured before. Similar: strange and anti-strange quark densities

Weak Currents - Valence Quarks (d_v, low x)

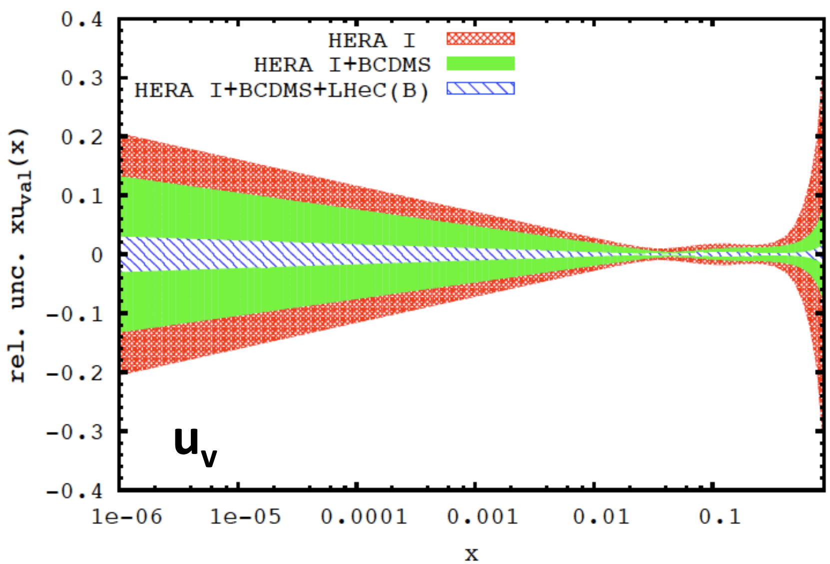


← from + CC

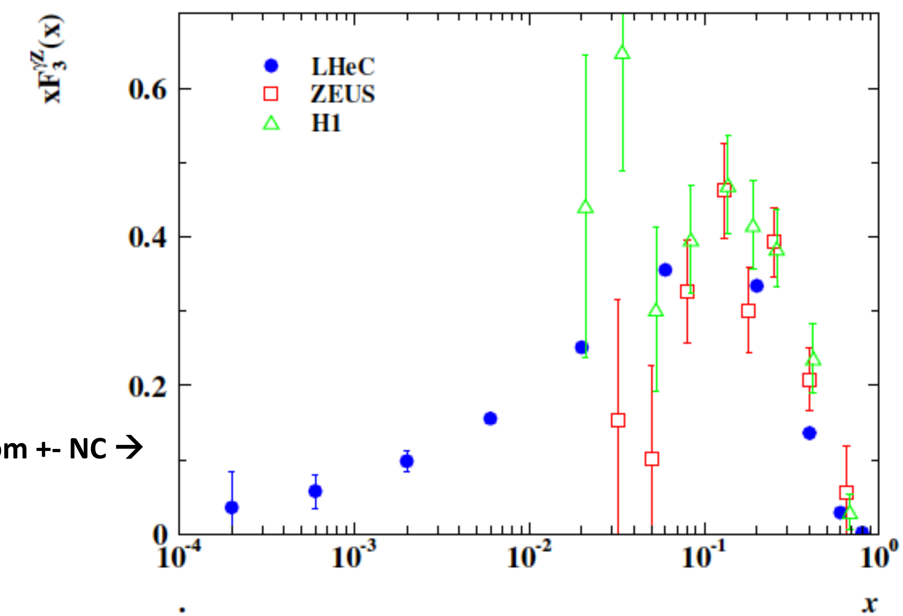
The valence quarks are still not well known, because of nuclear and non-pert. corrections.

Uncertain are particularly the d-valence and the low x region, which are important for LHC discovery and precision physics (M_W)

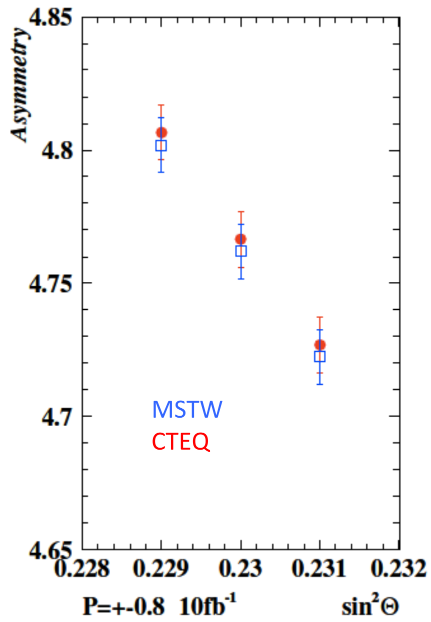
The LHeC needs positrons for both d_v at high x (from CC scattering at high luminosity, $10 fb^{-1}$) and for a measurement of $2u_v+d_v$ at low x (from the NC charge asymmetry with few fb^{-1})

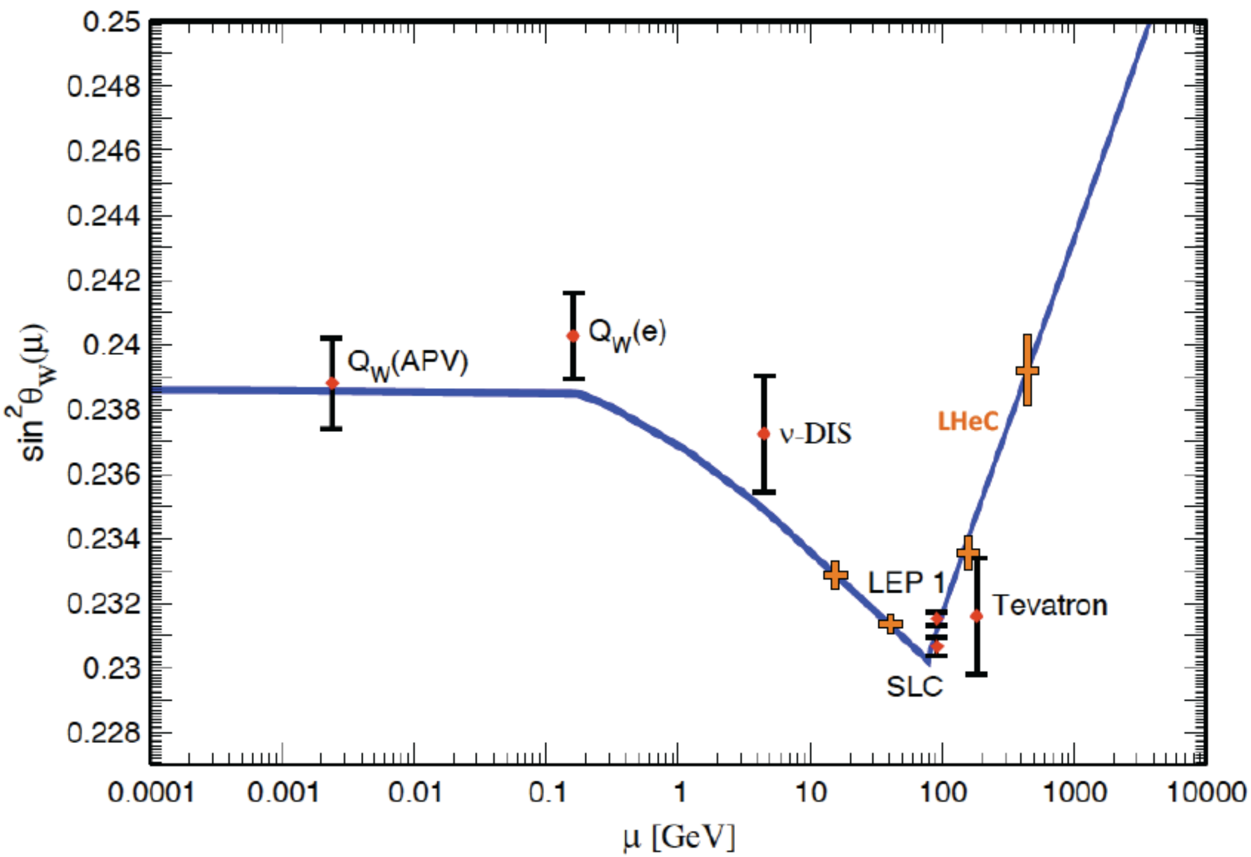


from +- NC →



Weak Neutral Currents – Polarisation Asymmetry



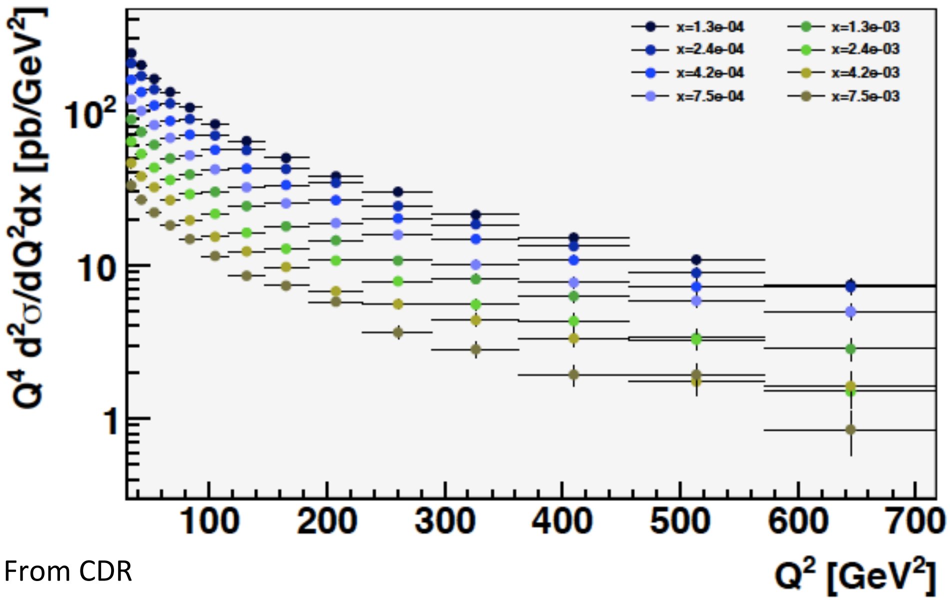


$$A^{\pm} = \frac{\sigma_{NC}^{\pm}(P_R) - \sigma_{NC}^{\pm}(P_L)}{\sigma_{NC}^{\pm}(P_R) + \sigma_{NC}^{\pm}(P_L)}$$

$$A^{\pm} \simeq \mp \kappa_Z a_e \frac{F_2^{\gamma Z}}{(F_2 + \kappa_Z a_e Y_- x F_3^{\gamma Z}/Y_+)} \simeq \mp \kappa_Z a_e \frac{F_2^{\gamma Z}}{F_2}.$$

Can measure running of the weak mixing angle to high precision with polarised e^-.
An example for electroweak physics w/o e^+.

Generalised Parton Distributions



From CDR

Figure 7.27: Simulated LHeC measurement of the DVCS cross section multiplied by Q^4 for different x values for a luminosity of 100 fb^{-1}, with $E_e = 50$ GeV, electron and photon acceptance extending to within 10° of the beampipe with a cut at $P_T^\gamma = 5$ GeV. Only statistical uncertainties are considered.

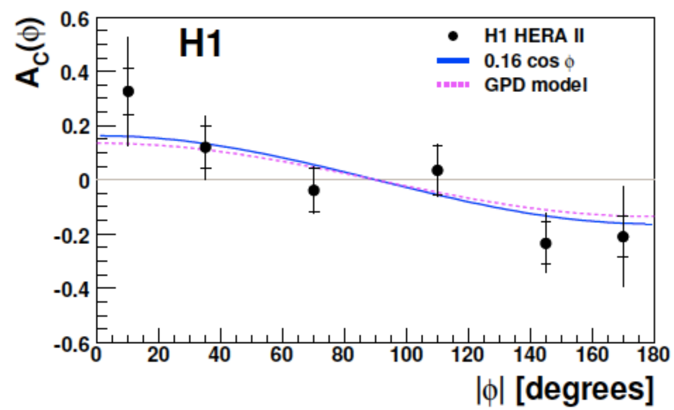
Gluon and singlet quark transverse imaging through DVCS measurements
ep → epγ

- Proton holography
- Parton amplitudes
- Spin puzzle

Precision requires ± with high statistics O(10fb^{-1})

$$A_C(\phi) = p_1 \cos\phi = 2A_{BH}\frac{\mathrm{Re}A_{DVCS}}{|A_{DVCS}|^2 + |A_{BH}|^2}\cos\phi.$$

H1 DESY 09-109   L=306 pb^{-1} $e^{\pm}p$ $Q^2 > 6.5$ GeV^2



Saturation of the gluon density - F_L

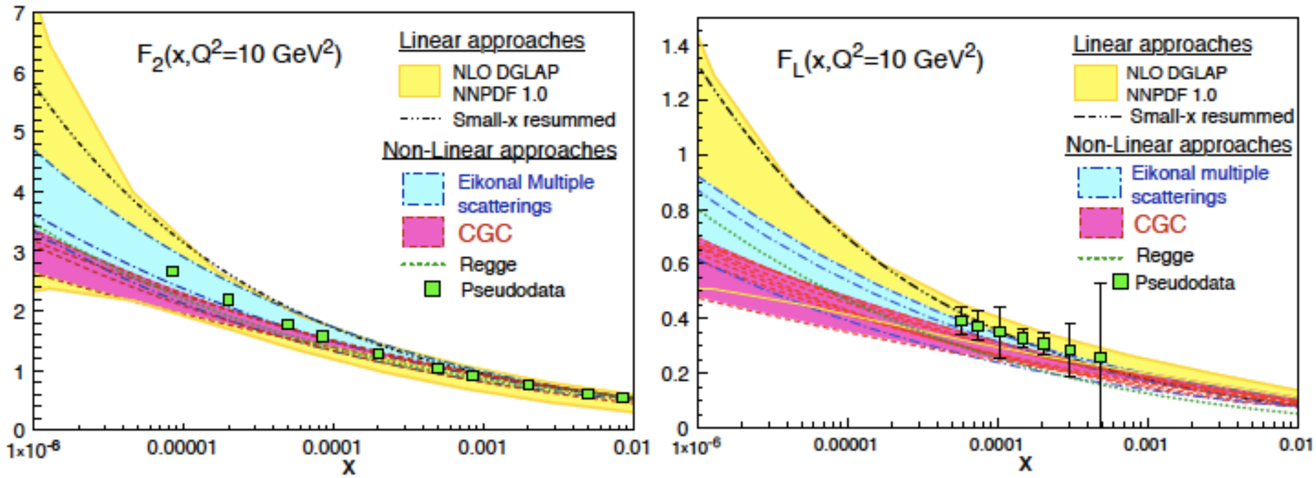


Figure 7.12: Predictions from different models for $F_2(x, Q^2 = 10\ \mathrm{GeV}^2)$ (plot on the left) and $F_L(x, Q^2 = 10\ \mathrm{GeV}^2)$ (plot on the right) versus x, together with the corresponding pseudodata.

Simulation of F_L with few fb^{-1} equivalent at different beam energies

High precision measurements of both F_2 and F_L are required to discover the saturation of xg at low x, and establish a new theory for non-linear parton evolution (replacing the DGLAP equations)

Precision for F_L requires to reach highest values of inelasticity $y = 1 - E'/E$, i.e. small E'

In order to cope with the background from hadrons (which is about charge symmetric unlike DIS) one needs to take data (O(100)pb^{-1}) with electrons and positrons of similar luminosity.

This measurement is also crucial in eA where the running times will be much shorter than in ep

Considerations

1. Beyond the SM: The LHC is the search+discovery machine (and hopefully successful). The LHeC delivers high precision and selectivity by the control of the initial state. Higgs with the LHeC demands maximum electron-proton luminosity.

2. The ± charged current reaction is sensitive to quark flavours and to particle/antiparticles, it selects top vs anti-top and strange vs anti-strange, for example. As a weak interaction it is sizeable only at high Q^2 and thus requires high luminosity.

3. The weak neutral current depends on the charge and the polarisation. Important electroweak measurements can be done with polarised electrons ($F_2^{\gamma Z}$), e.g. $\sin^2\Theta$. The full potential requires yet positrons too ($xF_3^{\gamma Z}$), e.g. light quarks.

4. At low Q^2 DVCS and F_L (also in eA) require high luminosity for electrons and positrons.

→ **There is a strong demand from physics to maximize the positron luminosity too**
(with probably less emphasis to the e^+ beam polarisation which is yet another complication)
→ **A setup with 100 fb-1 electrons and 1 fb-1 positrons is tolerable but requires L+ = O(L-/10)**

If the positron luminosity was much lower than for electrons, one would be tempted not to "waste" running time on positrons and thus the integrated luminosity came out to be even lower, relatively to electrons